Back to Basics: Theoretical Studies on Storm Clouds and Implications for Modeling

Research Highlight

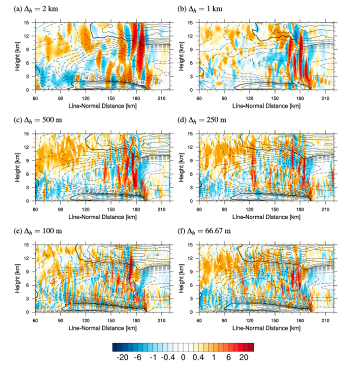
Storms associated with deep convection are a key component of weather and climate. For example, they produce a large share of precipitation that falls to the Earth's surface, and their anvil shields act as a thermal blanket on the planet.

To understand the behavior of these storms, researchers at the National Center for Atmospheric Research and University of Wyoming/Cooperative Institute for Research in Environmental Sciences showed that a simple mathematical scaling can describe the main effects of air pressure forces on storms. When the storms are wide and short, these pressure forces typically act like a lid on the vertical air motion within the storm. When the storms are tall and narrow, pressure effects are small and the vertical air motion can be relatively strong. This is important because the strength of the vertical air motion influences many storm characteristics. For example, it affects how cloud and precipitation particles grow and fall to the ground. The researchers showed that the simple mathematical scaling of these pressure forces closely matched with more detailed calculations that were run on a computer.

Cloud models divide a region of space into a multitude of grid cells and perform calculations at each cell. The size of these grids, called the grid spacing, is important because it determines the model's ability to explicitly represent features of a particular size. The researchers found that for grid spacings larger than about 500 m, the width of simulated storm updrafts is roughly proportional to the grid spacing. This means that the storms are artificially too wide at these resolutions because models cannot properly resolve them, leading to incorrect pressure effects and vertical air motion. The simple mathematical scaling was able to describe this behavior quantitatively. It was also shown that smaller-scale turbulent motions were resolved as the grid spacing was reduced below 250 meters. However, explicitly representing these motions was found to have little effect on the mixing of environmental air into the storms and overall storm characteristics. On the other hand, when the grid spacing was larger than 250 meters, much less environmental air was mixed into the storms compared to the higher resolution simulations.

Cloud models can be run in two-dimensional or three-dimensional mode. Two-dimensional models only simulate a slice of the atmosphere, making them much more computationally efficient than three-dimensional models. Thus, they remain widely used for research although the simulations may differ from those using three-dimensional models. To understand the effects of using two-dimensional versus three-dimensional models for simulating convective storms, the mathematical scalings describing air pressure effects were derived for both two and three dimensions. This work showed that the "lid" effect from air pressure forces is larger in two dimensions than three, which means that vertical air motion is weaker in two dimensions if all other conditions are the same. Differences between two and three dimensions are largest when the updrafts are moderately wide compared to their height. Differences in storm vertical air motion based on these mathematical scalings matched closely with the differences in two- and three-dimensional cloud model simulations.

Larger-scale weather and climate models that cannot resolve storms at all use convection parameterizations, which are a way of describing the effects of these storms based on the conditions in their environment, because the grid spacing in these models is too coarse to simulate the storms themselves. Parameterizations represent the physical processes driving storms, including the effects of air pressure forces. The mathematical scaling provides a very simple yet physically based way of including these effects, which are treated in an ad hoc manner in most current parameterizations.



Vertical cross section of a modeled deep convective storm (a type of storm called a squall line). Color contours show vertical air motion (units of m/s). Black contour lines indicate horizontal wind speed. The panels show simulations using different horizontal grid spacings as labeled.

Pressure forces in convective storms are important for influencing storm characteristics. A simple mathematical scaling of these pressure forces was derived, which helps to explain the behavior of cloud models as their grid spacing is modified. In addition to incorrectly representing pressure effects because simulated storms are too wide when the model grid spacing is larger than about 500 meters, models at these resolutions do not mix enough environmental air into the simulated storms. This has important consequences for the vertical transport of moisture, chemical constituents, and other quantities in models.

Reference(s)

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Cloud Life Cycle